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High Power Combining of Ka-Band TWTs for Deep Space Communications

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Abstract: This paper presents the results of a high efficiency power combining demonstration of two 100 W Ka-band space TWTs using a 4-port magic-T hybrid junction-based waveguide circuit. Power combining efficiencies of about 90% over a 1 GHz frequency band centered at 32.05 GHz and a high data transmission rate of 622 Mbps were successfully demonstrated.

Keywords: power combining; traveling wave tubes; Ka band; space communications; waveguide hybrid junctions

Introduction

Ka-band communications architectures at 32 and 37 GHz for future NASA space exploration missions are being proposed which may require data rates as high as 1 Gbps for the transmission back to Earth of large volumes of scientific data. Because of the large distances and antenna size limitations, the high data rates dictate the need for wide bandwidth and possibly transmitter powers of 1 kW or more. High electrical efficiency is also a requirement. The primary Ka band is the Deep Space Network (DSN) 500 MHz band of 31.8 to 32.3 GHz. One approach to achieving the high transmitter power and data rates is with the 4-port magic-T hybrid junction-based Ka-band power combiner architecture that was successfully demonstrated (≥90% efficiency) at NASA GRC in a 2-way combiner with two 110-115 W ACTS TWTAs over a 500 MHz frequency band of 29.1 to 29.6 GHz [1], [2]. The 2-way combiner can be extended in a binary configuration to 2^n TWTs, where n is an integer, to achieve higher powers. Reported here are the results of a demonstration of high efficiency power combining using two 100W Ka-band TWTs (L-3 Com model 999H) designed for high efficiency operation (≥55%) over the DSN frequency band [3]. Power combining efficiencies of about 90% and a high data transmission rate of 622 Mbps were successfully demonstrated. This work was supported by NASA Project Prometheus.

Power Combiner Test Circuit: The two-way power combiner test circuit is shown in Figure 1. The RF signals from two coherent TWTs at the input ports of the magic-T add and cancel in phase at the two co-planar output ports (sum and difference ports, respectively). A balance of input powers and phases, achieved by means of the variable attenuators and phase shifter in the RF input circuits, is essential for a maximum power at the sum port and simultaneously a minimum at the difference port. Figure 2 shows the variation of sum and difference output powers with difference in phase.

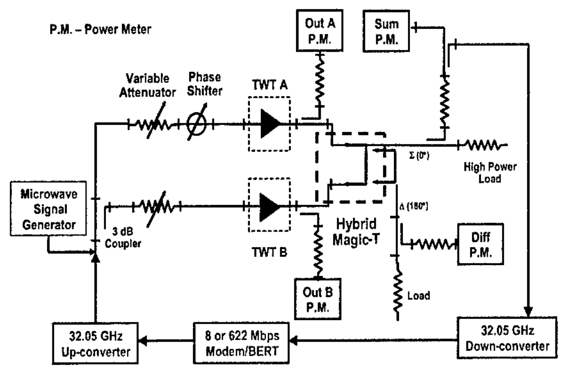

Figure 1. Two-way power combiner test circuit

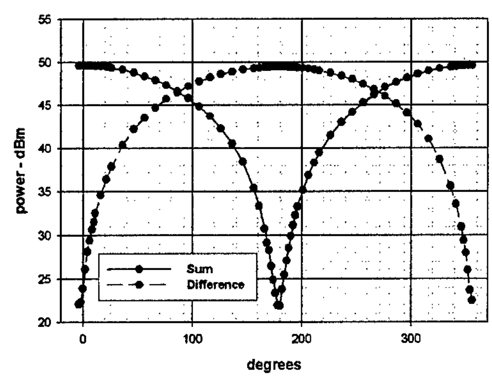

Figure 2. Magic-T sum and difference output power variation with change in phase difference.

Power and Efficiency Measurements: Typical power measurement results are shown in Figure 3, which compares the combined and individual TWT saturated powers over a 1 GHz frequency band centered at 32.05 GHz, at which the input powers and phases were initially balanced prior to the frequency sweep. The corresponding combiner efficiencies (~90%) for the 1 GHz band are shown in Figure 4. The combiner efficiency over the DSN frequency band was between 89.7 % and 90.8%. Figure 5 shows the power transfer curves for the individual TWTs and combiner at 32.05 GHz. Combiner efficiency was the same (~90%) for both linear and saturated power regions. Recent computer modeling of hybrid junctions at NASA indicates that improvements of up to 5% in combining efficiency are possible using a magic-T optimized for low loss and high power handling [4].

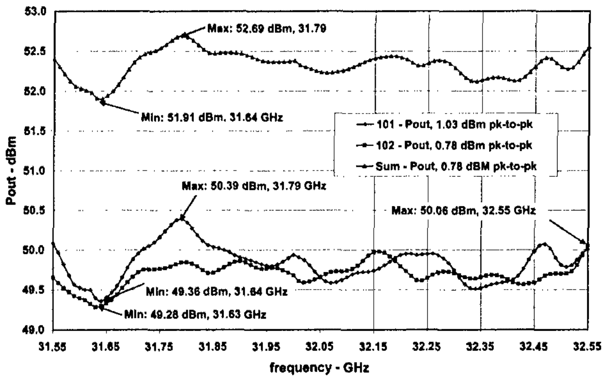

Figure 3. Comparison of combined and individual TWT saturated powers over a 1 GHz frequency band.

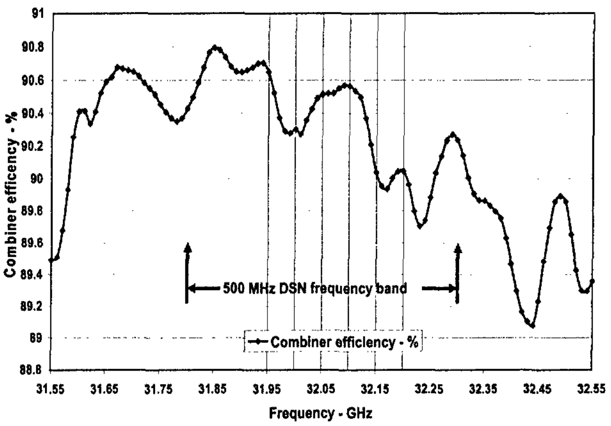

Figure 4. Combiner efficiency over a 1 GHz frequency band.

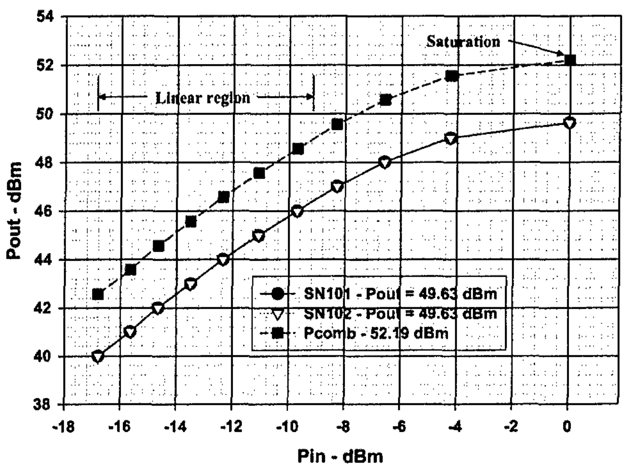

Figure 5. Individual TWT and combined output powers at 32.05 GHz.

Data Transmission Measurements: The circuit configuration for the data transmission measurements (carrier frequency of 32.05 GHz) is also shown in Fig 1. Error-free data rates of 8 Mbps (uncoded BPSK and QPSK) were observed. Because of the narrow signal bandwidths (8 and 4 MHz), variation in combiner power amplitude was negligible. This was not so for the 622 Mbps signal (QPSK) where a bandwidth of 311 MHz was needed. The reason can be seen in Fig 6 where the 3dB bandwidth was only about 200 MHz and the amplitudes at the 311 MHz band edges were about -15 dB. The cause of this was a large difference in electrical lengths between the two TWT paths and the corresponding large difference in rates of change of phase with frequency ($\Delta\varphi/\Delta f = 0.991$ deg/MHz). The disparity in electrical lengths was corrected and $\Delta\varphi/\Delta f$ was reduced to 0.147 deg/MHz. The resulting effect on the amplitude of the combined saturated power is shown in Fig 6. The main benefit was extending the useable bandwidth of the magic-T to that of the individual TWTs, which was observed out to at least 3 GHz. An important consequence was the successful transmission of 622 Mbps at a low BER of 2.4×10^{-8}.

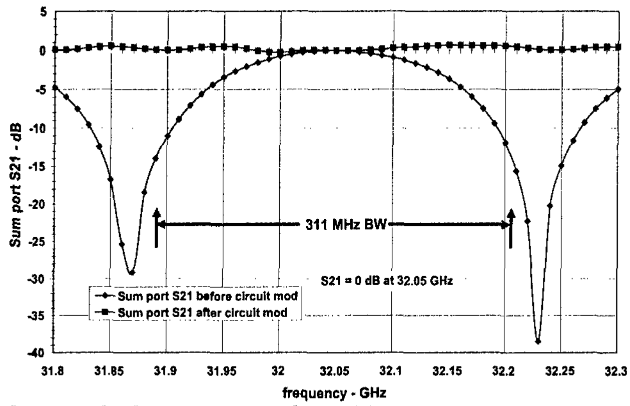

Figure 6. Comparison of combined saturated powers at sum port of magic-T before and after circuit modification.

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